CICE Consortium

Progress Report

February 2021 - February 2022

Overview

The CICE Consortium accomplished a number of major upgrades to our sea ice model code, scripts and testing infrastructure, while strengthening our visibility in the international modeling community. We released CICE versions 6.2.0, 6.3.0, and 6.3.1, all of which include updated releases of Icepack (versions 1.2.5, 1.3.0, 1.3.1). Major new capabilities include advanced snow physics, improved atmospheric and oceanic coupling mechanisms, a probabilistic grounding scheme for landfast ice, a plastic potential for sea ice dynamics, a completely overhauled time manager, basic netCDF output for Icepack, and more robust and flexible scripts for running and testing the code. In addition, the CICE Consortium was named to the 2021 R&D100 list of top technology innovations and awarded their Gold Special Recognition for Corporate Social Responsibility.

A list of member institutions, their representatives, and their contributions to the Consortium is provided later in this document. Based on the Sponsors' recommendation, the National Aeronautics and Space Administration (NASA) was invited and joined the Consortium, sharing responsibility for Community Support with the National Center for Atmospheric Research. NASA engagement brings remote sensing expertise along with related datasets and tools to the Consortium. The Geophysical Fluid Dynamics Laboratory (GFDL) withdrew from institutional membership in the Consortium, recognizing that their participation is more suitable as a community member. Other NOAA divisions continue to participate, particularly OAR, NWS and the ESPC office. These organizational changes were approved by the Sponsors group on July 14, 2021. Ruth Preller recently retired from the Naval Research Laboratory, leaving a gap in the Executive Oversight Board (EOB), both as NRL representative and EOB Chair. The Consortium Lead will work with NRL to identify a new EOB member, and with the EOB to identify a new Chair.

Major initiatives and institutional milestones

The Consortium's primary goal is to accelerate model development for sea ice research and the adoption of those developments into operational codes at forecasting centers. Successes this year include

- DOE ported snow model to Icepack, the first step toward merging Icepack into E3SM
- NRL has incorporated CICE6 into the Navy Earth System Prediction Capability V2.
- NCAR has incorporated CICE6 into CESM
- ECCC has contributed several new capabilities for sea ice dynamics and is leading the C-grid effort needed by multiple institutions, while moving their systems to CICE6
- DMI has incorporated CICE6 at higher resolution in order to provide a better forecast for the ice service.
- IOPAN continues to support CICE6 in the Regional Arctic System Model
- NOAA has integrated and validated CICE6 in the Unified Forecasting System
- NASA joined the Consortium this year and is actively planning the next user workshop

Other institutions are adopting and using CICE and Icepack:

- UK researchers are working with the formdrag code in Icepack and will propose changes to it.
- AWI is running Icepack with reanalysis forcing and with MOSAiC measurements, and has offered to compare the new snow code in Icepack with observational data in the Southern Ocean.
- An effort to implement scale-independent dynamical forcing (shear/convergence for opening/closing) for Icepack is underway.
- An NSF-funded project will improve Icepack using data from MOSAiC.
- The Arctic Marine Forecasting System of Europe is using CICE (ARCMFC).
- CICE is being tested in several of NOAA's Operational Forecast Systems, including GLOFS (Great Lakes), ALCOFS (Alaska Coastal), and RTOFS (Real-Time Ocean Forecast System).

In addition to the major code additions and improvements listed below, the Consortium embarked on a new collaboration mode this year, driven by modeling centers' need for a C-grid option for sea ice dynamics in CICE. Most of the Consortium's member institutions (NOAA, ECCC, DMI, NCAR, NRL) are now using or moving toward C-grid ocean models, for which a compatible sea ice model is desirable for more effective ice-ocean coupling. However, no single institution had the resources needed to implement such a large capability on their own. In response, the Consortium instituted a C-grid working group, discussed the relevant issues with outside experts, created a series of design documents, and implemented the code through two intensive "coding camps" in November and February. The new capability is nearly ready to be merged into the main CICE repository, where it will undergo further testing and tuning in concert with community users. This exercise is a prime example of multiple institutions working together to accelerate model development and its transfer into operational use.

Major improvements for Icepack since February 2021 include

- Advanced snow physics: redistribution by wind and wet/dry snow metamorphism
- Improved coupling mechanisms for under-ice drag, staggered atmospheric levels
- NetCDF history output

CICE model development highlights include

- Probabilistic grounding scheme for landfast ice
- Completed transition to JRA-55 forcing with newly spun-up initial condition files, a JRA-55 dataset generation tool, and deprecation of the CORE forcing option
- Validated EVP (1D) kernel, now also fully supported
- Dynamics code refactorization in preparation for physics and numerical options upgrades
- Plastic potential for VP and EVP

Software engineering upgrades include

- New CICE time manager
- Improved OpenMP performance
- Increased code testing coverage, to 76% in mid-2021 from 68% in summer 2020
- Github Actions for automated testing on Pull Requests and Pushes
- Conda package updates for user-friendly machine ports

Home page	https://github.com/CICE-Consortium
Zenodo Community	https://zenodo.org/communities/cice-consortium
Resource Index	https://github.com/CICE-Consortium/About-Us/wiki/Resource-Index
Forum	https://bb.cgd.ucar.edu/cesm/forums/cice-consortium.146/
CICE repository	https://github.com/CICE-Consortium/CICE
CICE releases with lists of enhancements and bug fixes	https://github.com/CICE-Consortium/CICE/releases
Icepack repository	https://github.com/CICE-Consortium/Icepack
Icepack releases	https://github.com/CICE-Consortium/Icepack/releases
Project boards	https://github.com/CICE-Consortium/CICE/projects
Trunk from subversion repository	https://github.com/CICE-Consortium/CICE-svn-trunk
Archived subversion repository (private, requires permission)	https://github.com/E3SM-Climate/CICE-archive

2021 Work Plan Updates

The following text updates the status of each of the items we called out in our 2021 Work Plan.

Tasks completed

Move to JRA-55 for all reanalysis forced tests
The transition to JRA-55 forcing is complete except for tests that require binary input data, because we are only offering JRA-55 forcing in netCDF format. We decided to continue testing gx3 configurations using the original binary data, which is not high enough quality for useful production runs, and deprecate the rest of the old binary data. We completed a 5-year demonstration run for sample output using JRA-55 forcing, including creation of a new mixed layer forcing file.

Port new snow-on-sea-ice model from E3SM
Advanced snow model capabilities have been ported from E3SM, the first step in a larger effort to merge Icepack with E3SM's column physics for use in E3SM. The new snow physics will need to be tuned in coupled systems: A multiyear simulation using the new snow code increases summer sea ice extent in both hemispheres, and the snow is much thicker, most likely due to the much smaller snow grain size now used for freshly fallen snow.

Redesign the CICE time manager
The old time manager was difficult to use, requiring users to calculate the number of timesteps needed in a run. Users now input the number of years, months, days or timesteps needed, and the timestep counter is now diagnostic. Additionally, a leap-year inconsistency between the run and forcing time axes was fixed.

netCDF for Icepack
We now have a basic netCDF implementation in Icepack, which can be upgraded as users request functionality.

Institute unit tests where it makes sense
Unit tests have been added as needed to either test code that is not normally covered or to validate particular methods, checking outputs generated by the subroutines based on well defined inputs. The unit tests are part of our test suite, and each unit test has its own top level driver, written in Fortran, that defines input data, calls CICE methods, and checks the results. These tests both validate the methods and cover methods that may not yet be used in CICE. New unit tests include

- calchk - validates the CICE calendar over a range of 100,000 years for the various CICE calendars including noleap and gregorian. A unit test is critical for checking the accuracy and robustness of calendar implementation over a wide variety of dates due to challenges with accumulation and roundoff errors. This could not be accomplished in CICE robustly outside a unit test due to cost.
- gridavgchk - checks methods that average fields from one grid stagger to another in CICE. Some of the grid averaging options are not yet used in CICE, so the unit test covers all cases robustly for well defined test data.
- bcstchk - checks the CICE broadcast infrastructure.
- sumchk - checks the CICE global sum infrastructure, checking diverse sum methods that affect performance and reproducibility on different pe counts. It also tests the minval and maxval infrastructure across the same types of input data.

CICE and Icepack physics bug fixes and software upgrades

Test suites have been greatly expanded to improve coverage of code and test physics options' interoperability. These upgrades identified several issues, such as a problem in the new snow model when debugging with initialized NANs, which was fixed. Likewise a parallelization problem when advection is off and some output conversion errors were fixed, and some function calls were reordered for improved physical consistency. In addition to repository maintenance and enhanced capabilities mentioned elsewhere, there also have been several improvements for Icepack namelists, staggered atmospheric boundary layer levels, the error tolerance for a rare mushy thermo failure, and bug fixes in the zsalinity parameterization. CICE PRs included bug fixes and enhancements for changes to Icepack, block sizes, history, quality control testing, elastic-anisotropic-plastic restarts and computational efficiency, the ice rheology, and NUOPC drivers.

Completed Pull Requests
From February 2021 through February 2022, the Consortium team submitted, reviewed and merged 98 Pull Requests (PRs) into the CICE and Icepack repositories, about 3.3 per week. 68 PRs were merged for CICE and 30 for Icepack, for the completed tasks above and continuing work below. Many additions and corrections were also made to the About-Us repository and all of the wikis.

Continuing or ongoing tasks

Implement C-grid option
As noted above, a working group established to address Consortium members' needs for a C-grid option has made excellent progress. This task was undertaken in the Software Engineer's CICE fork, to avoid conflicts in the main repository, and will soon be merged back into the main repository for further testing

and tuning in coupled modeling systems. For internal testing we implemented many new, idealized testing configurations (analytical solutions in 1D channels, symmetry, grid decompositions, various coastlines, previously published test problems, etc), which turned up some bugs in existing code. The first intensive coding camp was hybrid, with members meeting in Montreal and Boulder in November, 2021. A second, virtual coding camp was held in February 2022. Participants generally focused on their team responsibilities, e.g. ECCC and DMI worked on the discretizations, NOAA worked on the underlying infrastructure, NRL developed testing infrastructure, NCAR ran tests and debugged code, and LANL made code structure decisions and provided technical advice.

Increase code coverage of test suites

The fraction of CICE code covered by our tests is 76.33% for CICE and 76.85% for Icepack. Most of our coverage testing is done by running realistic configurations (e.g. gx3) with various physical or infrastructure setups, which verify that the code produces reasonable (not necessarily correct) results. We continue to evaluate and improve our testing coverage and infrastructure.

Residual ice

NOAA/NWS highlighted a residual ice issue in its testing, in which large expanses of very low ice concentrations remain. This ice most likely does not matter much for simulations but can be problematic for users, e.g. forecasting probable ice thickness for ships. In climate models these low concentrations have simply been ignored. The problem is likely a mismatch in limiting parameters used for numerical stability, where thermodynamics uses a thickness based parameter and dynamics uses a mass based parameter, leaving a range of very small volumes with no way to remove them. Physics-based and numerical solutions are being explored.

Redesign or update Icepack interfaces to account for needs of DOE's E3SM

We have continued to implement the new interface design (from last year) as new code comes in; older code needs to be brought in line with design. This effort will be a major component of the E3SM column physics/Icepack code merge.

Merge Icepack with E3SM column physics

The column physics code in E3SM and Icepack have diverged substantially over the past 5-6 years. Discussions about whether to bring them back into alignment led to the following agreement: with assistance from the Consortium, E3SM sea ice modelers will continue to merge changes from MPAS-SI into Icepack, streamline Icepack by deprecating older code, complete ongoing driver-column physics interface changes to simplify Icepack installation in other drivers such as MPAS-SI, and then merge Icepack back into MPAS-SI with requisite testing. In addition, meetings to discuss coupling issues (Icepack mushy thermodynamics and frazil ice formation) and more generally, coupling quantities and procedures with E3SM, NCAR/CESM, and DoD/NRL, are ongoing.

Improve OpenMP threading throughout the code

Many task threading directives in CICE were commented out due to inconsistent behavior across machines and compilers. OpenMP was updated and validated, is now more robust, and performance improved. Part of the solution involved recognizing differences in the default OpenMP environments across machines and overriding some default settings.

Improve build system

The scripts that configure and build the working directories and executable code are robust and stable, although we continue to find ways to improve them in relatively small ways.

Improve automation of testing, documentation
This year we transitioned automated software testing of CICE, Icepack and their documentation files to Github Actions from TravisCI, which began limiting the free functionality available to open source repositories. GitHub Actions is working well.

Code and documentation maintenance
As a result of increased diversity awareness and sensitivity, we changed the primary code branches in github from “master” to “main”. This is an ongoing task, which includes necessary changes to CICE associated with changes to Icepack; fixes to errors in documentation, machine and build scripts; and broader testing, e.g. numerous uninitialized variables were identified by snan testing. We also increased namelist flexibility to reduce code aborts when reading them out of order, and we updated NUOPC drivers for modeling centers’ configurations.

Institute unit tests where it makes sense
A unit testing capability has been added to the code with several unit tests, as noted above. We also plan to develop unit tests for halo updates and dynamics kernels, to be implemented as time allows.

Add iceberg grounding interactions for fast ice
An iceberg grounding scheme for creating landfast ice was investigated and found to not work as well as expected in a 5-km resolution configuration. Therefore the project’s priority was lowered, pending further investigation.

Add Mohr-Coulomb rheology
The EVP dynamics code was refactored to make the viscosities explicit, which will enable alternative rheological formulations such as Mohr-Coulomb, and implemented a plastic potential for both VP and EVP, which decouples the yield curve and flow rule. Work on the rheology itself is ongoing and not yet ready to be shared with the Consortium.

Create kernels for EAP similar to EVP
Regression failures in EAP have been debugged and the code cleaned up, readying it for kernelization. Refactoring this code is pending a broader design for all of the dynamics drivers and options, anticipated as part of the new C-grid effort. Work on the 1D EVP option for GPU/KNL architectures also continued.

Code deprecation efforts
To reduce code complexity and encourage use of better physical parameterizations, we instituted a deprecation process last year and identified a number of parameterizations and forcing data sets to deprecate. However, nothing was deprecated because users either wanted to keep the simpler functionality for comparison purposes or because we were unsure of the ramifications for other parameterizations of removing a simpler one. The deprecation process, even when it’s not completed, helps us determine how the community is actually using the code. This year we will deprecate some older options in Icepack and also the older forcing datasets no longer needed for testing CICE and Icepack. Deprecated code will remain available in our repositories, and deprecated data will continue to be accessible from our zenodo community site.

Postponed activities
Several tasks have been postponed while projects at various institutions proceed; what the Consortium accomplishes is highly dependent on development and implementation of research programs at the participating institutions, which the Consortium itself doesn't control. However, we check in regularly on progress and will work with them when new code capabilities are ready for testing and inclusion in the

Consortium’s repos. Examples include the satellite emulator, the variational ridging scheme, and wave-sea ice interactions.

Community Support

Our first workshop and tutorial were held in early 2020, just prior to the pandemic lockdown. In 2021, we responded to an U.S. Interagency Arctic Research Policy Committee (IARPC) request regarding future directions for sea ice science, and we provided some of our R&D100 graphics for IARPC use to Renu Joseph (DOE). We also initiated broader discussions of thickness biases in various model centers’ configurations and use of MOSAiC data for testing Icepack. 2022 promises additional community engagement through a User Workshop and IARPC, as noted below.

General information	https://github.com/CICE-Consortium/About-Us
How to contribute	https://github.com/CICE-Consortium/About-Us/wiki/Contributing
General information wiki	https://github.com/CICE-Consortium/About-Us/wiki
Resource index	https://github.com/CICE-Consortium/About-Us/wiki/Resource-Index
Icepack wiki	https://github.com/CICE-Consortium/Icepack/wiki
Icepack documentation, user guide	https://readthedocs.org/projects/cice-consortium-icepack/
CICE wiki	https://github.com/CICE-Consortium/CICE/wiki
CICE documentation, user guide	https://readthedocs.org/projects/cice-consortium-cice/
Zenodo Community (DOIs)	https://zenodo.org/communities/cice-consortium
Workshop and Tutorial	http://www.cesm.ucar.edu/events/2020/cice-icepack/ http://www.cesm.ucar.edu/events/2020/cice-icepack/coursework.html

Visibility

In addition to the 98 Pull Requests noted above for February 2021-February 2022, there are 94 CICE forks of the main repository and 87 Icepack forks. Since its inception on December 27, 2018, our user forum has received 360 messages in 74 different threads.

A major accomplishment this year was successfully entering the R&D100 competition hosted by R&D World, honoring “revolutionary ideas in science and technology.” The CICE Consortium was recognized among the top 100 innovations in 2021 and in addition, was awarded the Gold Special Recognition for Corporate Social Responsibility, which “honors organizational efforts to be a greater corporate member of society, from a local to global level.” Our entry team included all Consortium member institutions as well as three academic institutions that have contributed substantially to the code: University of Washington, University of Reading, and the Naval Postgraduate School. Los Alamos National Laboratory produced a video in support of the R&D100 entry: https://www.youtube.com/watch?v=WxuCo15 Gy8. As part of this effort we also updated the Users/Publications list: see https://github.com/CICE-Consortium/About-Us/wiki/Users-and-Citations.

Publications

Bouchat, A., Hutter, N., Chanut, J., Dupont, F., Dukhovskoy, D., Garric, G., et al. (2022). Sea Ice Rheology Experiment (SIREx), Part I: Scaling and statistical properties of sea-ice deformation fields. *Journal of Geophysical Research: Oceans*, 127, e2021JC017667. https://doi.org/10.1029/2021JC017667

Hutter, N., Bouchat, A., Dupont, F., Dukhovskoy, D., Koldunov, N., Lee, Y., et al. (2022). Sea Ice Rheology Experiment (SIREx), Part II: Evaluating linear kinematic features in high-resolution sea-ice simulations. *Journal of Geophysical Research: Oceans*, 127, e2021JC017666. https://doi.org/10.1029/2021JC017666

Mehlmann, C.,, S. Danilov, M. Losch, J.F. Lemieux, N. Hutter, T. Richter, P. Blain, E.C. Hunke, P Korn Simulating linear kinematic features in viscous-plastic sea ice models on quadrilateral and triangular grids with different variable staggering. JAMES, 13, 2021. http://dx.doi.org/10.1029/2021MS002523

Zampieri, L., F. Kauker, J. Froehle, H. Sumata, H.F. Goessling and E. Hunke (2021). Impact of sea-ice model complexity on the performance of an unstructured-mesh sea-ice/ocean model under different atmospheric forcings. Journal of Advances in Modeling Earth Systems, 13, e2020MS002438. https://doi.org/10.1029/2020MS002438

Holland, M., and E. Hunke, Arctic Sea Ice in Large-Scale Earth System Models, Oceanography, in press 2022.

“A tool for modeling changes in sea ice”, Los Alamos National Laboratory News Brief, https://www.lanl.gov/discover/science-briefs/2021/March/0322-cice.php

Presentations

Rick Allard, D. Hebert, J. May, E. J. Metzger, J. Shriver, T. Townsend, J. Crout, M. Phelps, O. M. Smedstad. Modeling sea ice and ocean circulation in the Arctic. US CLIVAR Phenomena, Observations, and Synthesis Panel Summer Meeting, August 2021

Rick Allard, D. Hebert, J. May, E. J. Metzger, J. Shriver, T. Townsend, J. Crout, M. Phelps, O. M. Smedstad. Sea Ice Assimilation in Navy Modeling Systems. International Earth Surface Working Group Seminar, September 2021

Rick Allard, D. Hebert, J. May, E. J. Metzger, J. Shriver, T. Townsend, J. Crout, M. Phelps, O. M. Smedstad., N. Barton. Navy Earth System Capability (ESPC). Goddard Applied Sciences Seminar, October 2021

Rick Allard, G. Panteleev, D. Hebert, E. Douglass, J. Dykes. Development of spatially-varying grounding coefficients for landfast ice in CICE6, AGU Ocean Sciences Meeting, February 2022

Robert Grumbine. Thoughts on evaluating sea ice models. COSIM seminar, Los Alamos National Laboratory, March 2021

Elizabeth Hunke, Modeling sea-ice for climate research and short-term forecasting. XCP Summer School, LANL, June 2021

Elizabeth Hunke, Modeling sea-ice for climate research and short-term forecasting. Coupled Global Modeling Working Group, NOAA, May 2021

Elizabeth Hunke, Modeling sea-ice for climate research and short-term forecasting. LANL/Arizona Days, May 2021

Elizabeth Hunke, Modeling sea-ice for climate research and short-term forecasting. SIAM & IMA Student Chapter, University of Nottingham, UK, April 2021

Elizabeth Hunke, CICE Consortium: Advancing sea ice modeling. CESM Annual Workshop, Boulder CO, June 2021

Elizabeth Hunke, CICE Consortium: Advancing sea ice modeling. American Geophysical Union Fall Meeting, December 2021 session “C55B: Community Tools and Products for Cryosphere Discovery and Application II Poster”

Elizabeth Hunke, Briefing for DOE Arctic Energy Office, March 3, 2022

Elizabeth Hunke, Briefing for Interagency Arctic Research Policy Committee, March 7, 2022 https://zenodo.org/record/6335509

Alek Petty. New insights into the polar sea ice-ocean state from NASA’s Operation IceBridge & ICESat-2 COSIM seminar, Los Alamos National Laboratory, October 2021

Forum	https://bb.cgd.ucar.edu/cesm/forums/cice-consortium.146/
Zenodo community	https://zenodo.org/communities/cice-consortium
Github government community	https://government.github.com/community/#research

Plans

The Consortium is planning a hybrid user workshop for 2022, partly to support the Biannual Implementation Plan for Monitoring, Observing, Modeling, and Prediction, a Foundational Activity in the IARPC Arctic Research Plan for 2022–2026. One of their objectives is to “Increase coordination and engagement between federal activities and international and non-federal partners who are conducting monitoring, observing, modeling and prediction of the Arctic”. For IARPC, the Consortium has offered to coordinate and report on three activities:

- a community workshop to discuss sea ice modeling needs and priorities across the research and operational modeling communities
- implementation of a new C-grid modeling capability for CICE, needed by multiple modeling centers for effective ice-ocean coupling with their C-grid ocean models
- creation of a test suite using MOSAiC and other observational data to drive the Icepack sea ice column physics model in Lagrangian studies.

These three bullets might change as the Biennial Implementation Plan is further developed.

A conversation on the Forum has highlighted the possibility of curating more forcing datasets for Icepack from the community, partly to prevent duplication of effort, if possible, or at least provide a wiki page with instructions for obtaining the data and configuring the model to use them. While we do not want to encourage the model (Icepack or CICE) to be run in stand-alone mode, Icepack itself is quite popular for Lagrangian studies, and the Consortium plans to coordinate MOSAiC data for use in Icepack, similar to the SHEBA forcing data set that we currently have but including more data such as biogeochemistry. However, MOSAiC data is mostly embargoed through this year. NOAA is also interested in hierarchical system testing for UFS.

The 2022 user workshop will not include a tutorial. We are working through some challenges associated with the 2020 workshop tutorial, e.g. international attendees weren't funded to participate, and supercomputer facilities were needed to demonstrate fully coupled climate modeling issues. Part of the tutorial materials could be made more accessible for self-study on our wiki; a major uncertainty is where the code could be reliably run, e.g. in the cloud.

Code deprecation has been a challenge due to the broad variety of users and uses, while streamlining code for use in coupled configurations is a high priority for some modeling centers, especially E3SM. To maintain the Consortium's relevance for E3SM, E3SM's column physics is being merged with Icepack, and as part of this process, some older code will be deprecated. Moreover, Icepack interface changes will be completed, to reduce the impact on model drivers when installing Icepack. We plan to follow the code deprecation process initially envisioned, which alerts the community to upcoming changes before they become permanent, and we will focus only on Icepack for now. A working group will create a design document to share with E3SM and other concerned parties, discussing and prioritizing the options.

A discussion of longer-term community needs in the face of several new, competitive sea ice models revealed that maintaining Icepack as our main product and letting CICE become just a testbed for Icepack is not a viable option for the community. The CICE user community including Consortium members expect to benefit by having a C-grid dynamical core, development of which is underway. Looking toward the future, providing (parts of) the dycore on an unstructured mesh would provide the most flexibility, even if most community members will be using structured C-grids for the next several years, and we will consider opportunities to move toward unstructured meshes.

The Consortium's task list is constantly changing as tasks are completed and new ones arise, many to address issues submitted by external community members. Critical tasks for code releases are organized into project boards. Ongoing, longer term tasks include continuing to automate the test suites and documentation, deciding if and how data assimilation capabilities that have been developed could be included in the Consortium's repositories, and incorporating other community enhancements as they become available. Another set of longer term tasks of interest to all of our Consortium member institutions and the broader community involves enhancing our metrics and analysis capabilities. The Consortium can assist in coordinating community efforts, e.g. the NSF MOSAiC project mentioned above and NOAA's establishment of formal metrics for UFS, which is being led by EMC and NCAR under NOAA support.

Most Consortium activities involve team members from multiple institutions, overseen by the institution responsible for the relevant Consortium Team but often led by people at other institutions. Ongoing and future work in the table below includes some items mentioned above.

Table of Plans

Team	New and ongoing effort	Lead	Future work	Lead
Testing and Analysis	Begin development of a CICE Consortium diagnostics package	NRL NOAA	Include metrics and scripts for verification against MOSAiC and other observations	LANL NOAA NASA
	Increase code coverage of test suites	NOAA IOPAN	Implement MOM6 test domains/cases for CICE	NCAR
	Institute unit tests where it makes sense	NOAA	Create test options with major centers' namelist configurations.	NRL
			Incorporate the satellite emulator developed by Navy/DOE	LANL
CICE dynamical core	Add Mohr-Coulomb rheology	ECCC	Create kernels for EAP similar to EVP	DMI
	Add iceberg grounding interactions for fast ice	DMI	Refactor the dynamics code to have unique drivers	DMI ECCC
	Implement C-grid option	ECCC	Optimize implicit (VP) solver	ECCC
	Integrate C-grid into NOAA UFS	NOAA	Integrate C-grid into Navy GOFS and ESPC systems.	NRL
Icepack	Port Icepack developments from E3SM and elsewhere	LANL IOPAN	Add variational ridging scheme and interactions with the ice thickness and floe size distributions	LANL
	Create MOSAiC forcing, benchmarking and evaluation dataset for Icepack	LANL NCAR NASA	Improve radiation scheme using MOSAiC measurements	LANL
	Remove residual ice	LANL DMI	Fully implement conservation budgets	NCAR
Infrastructure	Refine Icepack interfaces and improve Icepack robustness and usability	NOAA	Develop boundary conditions for regional CICE configurations	DMI ECCC
	Debug and optimize threading	DMI NOAA	Create a user-friendly grid generation tool	NRL

Community Support	Improve online documentation	NCAR NASA	Document/publish coupling considerations, including thickness biases	LANL
	Improve processes for documenting how well new features have been tested and documented	NCAR NASA	Update tutorial for online learning	NCAR NASA
	Plan and hold a user workshop	NCAR NASA		
General	Address issues and user questions as needed			All
	CICE: https://github.com/CICE-Consortium/CICE/issues			
	Icepack: https://github.com/CICE-Consortium/Icepack/issues			

Challenges

We need a more robust process for new feature testing and documentation. Although all new features currently must be documented in the User and Science Guides, we need additional documentation of how the new code was tested (which tests, compilers, architectures), what the results were, and some indication of aspects that weren't sufficiently tested (which must be defined). The extent of testing needed is somewhat case dependent, and we do not want to intimidate code contributors with excessive requirements. We will discuss adding more questions regarding testing to our PR template, which currently asks only for a link to standard test suite results.

Having to implement Icepack changes in Icepack's driver as well as CICE is a lot of work, and becoming more so as the two drivers diverge. A CICE configuration could be implemented that mimics Icepack's 4 grid cells, replacing the Icepack driver. To ameliorate modeling centers' concerns with the amount and complexity of code from our repositories that must be linked with their code bases, the CICE and Icepack repositories could be refactored so that some unwanted code (e.g. drivers unnecessary in coupled modeling centers' codes) would not have to be downloaded, while other code (e.g. the time manager) could be shared. For example, the column physics code in Icepack could itself be a separate submodule. This major change would save having to implement changes in both CICE and Icepack drivers, but would impact users who already use Icepack as a Lagrangian type of model. This discussion is ongoing while the Consortium moves forward on other tasks with the current repository layout.

In addition to the Icepack driver, there are many other drivers in the CICE repository for coupled modeling, each of which needs to be updated when there are changes to the standard, standalone driver. Individual developers are not able to test these drivers and could mess them up if blindly making changes; on the other hand, the code might not compile or run with the unmodified drivers. In an ideal world, we would have one driver that works for multiple configurations through cpp and namelist options. For now, each modeling center responsible for a given driver will update it as they incorporate a new CICE version in their systems, and the drivers will not be updated for every code modification.

Because the stand-alone CICE configuration starts from a not-very-spun-up initial condition that was designed just for software testing and does not include coupled feedback effects, it is not useful for scientific validation (although many sensitivity studies have been performed in the past). If one of our modeling centers produces a physically reasonable simulation in one of their coupled model configurations, we could consider offering a snapshot from it as an initial condition, but most other configurations will set different parameterizations and might not even be compatible, e.g. if there are different numbers of ice or snow layers. Therefore it's best for each modeling center to spin up and tune the simulation using their own configurations, rather than the Consortium providing a mechanism for validation.

Major agency contributions since February 2021

Agency/ Institution	**Sponsor, EOB Member**	**Team members**	**Contributions**
DOE/LANL	Xujing Davis, Renu Joseph Dave Bader	Elizabeth Hunke Andrew Roberts Nicole Jeffery	Project leadership and reporting (prioritization, planning, and oversight); Icepack updates esp. snow; visibility, code releases, Zenodo curation
NSF/NCAR	Anjuli Bamzai and Eric DeWeaver, Jean-Francois Lamarque	David Bailey Alice DuVivier Marika Holland	Community liaison, workshop planning, forum oversight and response, documentation; C-grid implementation, debugging
DoD/NRL	Dan Eleuterio, Ruth Preller (EOB Chair)	Rick Allard David Hebert	Test design/ implementation, JRA-55 forcing data; C-grid testing
NOAA/OAR/WPO	Arun Chawla	Tony Craig (contractor funded by NOAA exclusively for general CICE support as software engineer and code manager)	Software engineering (SE), esp. Icepack interface, coupling infrastructure; run/build scripts, I/O; scheduled/extended testing, automation, code coverage, unit tests; new time manager; OpenMP threading; netCDF for Icepack; C-grid infrastructure; leads all code releases

NOAA/NWS	Hendrik Tolman	Bob Grumbine Bonnie Brown Mark Olsen Maureen Brooks Jessie Carman	Metrics development; administrative support; seminar
NASA	Thorsten Markus, Nathan Kurtz	Alek Petty	Workshop planning; seminar
ECCC	Pierre Pellerin	JF Lemieux Philippe Blain Frederic Dupont	Led C-grid effort; implicit VP solver; improved landfast ice parameterization, bathymetry data; SE support including conda environments, libraries, improved run/build scripts; documentation
DMI	Jacob L. Høyer	Till Rasmussen Mads Ribergaard	EVP kernel, dynamics testing; NUOPC cap; OpenMP threading; C-grid development
IOPAN	Slawomir Sagan	Robert Osinski	Testing in RASM for both forced and fully coupled configurations

Trackable Consortium Output

Products	**Identifiers**
Through June 2018	
CICE repository	http://doi.org/10.5281/zenodo.1205674
CICE v6.0.0.alpha release	http://doi.org/10.5281/zenodo.1205675
Icepack repository	http://doi.org/10.5281/zenodo.1213462
Icepack v1.0.0 release	http://doi.org/10.5281/zenodo.1215746
Icepack v1.0.2 release	http://doi.org/10.5281/zenodo.1213463
Roberts et al., *Phil. Trans. Royal Soc. A,* 2018	http://doi.org/10.1098/rsta.2017.0344
Allard et al., EGU Abstract	Geophysical Research Abstracts Vol. 20, EGU2018-9495, 2018

Through December 2019	
CICE v6.0.0 release	http://doi.org/10.5281/zenodo.1893041
CICE v6.0.1 release	http://doi.org/10.5281/zenodo.3351684
CICE v6.0.2 release	http://doi.org/10.5281/zenodo.3516944
CICE v6.1.0 release	http://doi.org/10.5281/zenodo.3568214
Icepack v1.1.0 release	http://doi.org/10.5281/zenodo.1890602
Icepack v1.1.1 release	http://doi.org/10.5281/zenodo.3251032
Icepack v1.1.2 release	http://doi.org/10.5281/zenodo.3516931
Icepack v1.2.0 release	http://doi.org/10.5281/zenodo.3568288
Through February 2021	
CICE v6.1.1 release	https://doi.org/10.5281/zenodo.3712304
CICE v6.1.2 release	https://doi.org/10.5281/zenodo.3888653
CICE v6.1.3 release	https://doi.org/10.5281/zenodo.4004992
CICE v6.1.4 release	https://doi.org/10.5281/zenodo.4359860
Icepack v1.2.1 release	https://doi.org/10.5281/zenodo.3712299
Icepack v1.2.2 release	https://doi.org/10.5281/zenodo.3888633
Icepack v1.2.3 release	https://doi.org/10.5281/zenodo.4004982
Icepack v1.2.4 release	https://doi.org/10.5281/zenodo.4358418
Blockley et al., *BAMS, 2020*	https://doi.org/10.1175/BAMS-D-20-0073.1
Hunke et al., *Curr. Clim. Change Rep.*, 2020	https://doi.org/10.1007/s40641-020-00162-y
Hunke, *SIAM News,* 2020	https://sinews.siam.org/Details-Page/the-challenges-and-opportunities-of-one-size-fits-all-sea-ice-models
Through February 2022	
CICE v6.2.0 release	https://doi.org/10.5281/zenodo.4671172
CICE v6.3.0 release	https://doi.org/10.5281/zenodo.5423913
CICE v6.3.1 release	https://doi.org/10.5281/zenodo.6314188
Icepack v1.2.5 release	https://doi.org/10.5281/zenodo.4671132
Icepack v1.3.0 release	https://doi.org/10.5281/zenodo.5423061

Icepack v1.3.1 release	https://doi.org/10.5281/zenodo.6314133
Briefing for Interagency Arctic Research Policy Committee, March 7, 2022	https://zenodo.org/record/6335509
Bouchat et al., *JGR Oceans*, 2022	https://doi.org/10.1029/2021JC017667
Hutter et al., *JGR Oceans*, 2022	https://doi.org/10.1029/2021JC017666
Mehlmann et al., *JAMES*, 2021	http://dx.doi.org/10.1029/2021MS002523
Zampieri et al., *JAMES*, 2021	https://doi.org/10.1029/2020MS002438